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A REVIEW OF THE LOUDON SURFACTANT FLOOD PILOT TEST

By
Dwight L. Dauben

November 1988

Performed Under Contract No. AC19-85BC10830

K&A Technology
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National Petroleum Technology Office
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SUMMARY

A review of the performance of the Loudon Surfactant Flood Pilot Test has been completed. This project was conducted by Exxon in the Loudon Field, Fayette County, Illinois, beginning in 1981. The project was conducted in a 0.68 acre 5-spot pattern, using four injection wells, one central producer, five observation wells, and one post-project cored well. The microemulsion was designed to be effective in the presence of the highly saline formation water (104,000 ppm TDS). No preflush was required.

The project recovered about 60 percent of the residual oil saturation within the pattern area, and oil cuts as high as 26 percent were attained. This recovery level is very high when compared to many other surfactant projects and is particularly significant in view of the high-salinity formation water.

The project was very well designed and executed. The pilot represents a breakthrough in technology and opens up the possiblities of using similar technology to recover oil from other relatively shallow, low-pressure reservoirs. The following are the major factors which contributed to the success of the project.

1. Use of a surfactant chemical system which can function in the presence of the formation water. Such a system avoids the need for a preflush to remove salinity and hardness.

2. Favorable reservoir conditions, including good interwell continuity, adequate oil saturation, high permeability, and small pattern size.

3. Good operating controls to avoid pressure parting of the formation and to insure that the desired quantity of fluids enters the pattern area.

The project was clearly interpretable. Information which contributed to a good interpretation came from use of core analysis, well log analysis, interwell tracers, monitor wells, and injection profile surveys.

Two operational problems occurred during the project: emulsion problems after surfactant breakthrough and bacterial degradation of the polymer. This project, along with others, points out the need for biocides which can effectively protect biopolymers from microbial degradation.

INTRODUCTION

The Loudon Field, operated by Exxon, is located in Fayette County, Illinois. At project initiation, the field had been subjected to 13 years of primary production and 30 years of waterflood production. Even after waterflooding, it was estimated that almost half of the original oil-in-place (OOIP) remained unrecovered.

An earlier surfactant flood pilot was initiated in 1969.[1] In that pilot, a large volume of low salinity preflush water was injected to pre-condition the reservoir for the micellar slug. This preflush was necessary to prevent the contact of the highly saline formation water (104,000 ppm) with the micellar fluid containing a petroleum sulfonate surfactant. Petroleum sulfonates cannot tolerate high salinity or high hardness fluids. The pilot test recovered only about 15 percent of the residual oil in the test area. Exxon concluded that preflushes to remove excessive salinity and hardness are not likely to be effective on a practical basis. Consequently, much of the surfactant flooding research has been directed toward the development of chemical systems capable of being effective in high salinity reservoirs without requiring a preflush. The pilot, initiated in 1981, used this type of chemical formulation.

The Loudon test was conducted under the Tertiary Incentive Crude Oil Program for a specified enhanced oil recovery technique. As part of that program, the operator is required to furnish to the Department of Energy an initial report with technical details and yearly updates on performance. Keplinger Technology Consultants, Inc. is evaluating many of the EOR projects conducted under the Cost-Shared and the Tertiary Incentive programs under a contract with the DOE. These evaluations are made available to the public.

The purposes of this report are to independently evaluate the performance of this project, to determine how the project could have been improved using advancements in the technology, and finally, to define critical areas of research that are needed to further develop the technology.

The primary sources of information used for this evaluation are from References 2 and 3. Reference 2 provides a good review of the project and its performance. This report summarizes the key points from that reference and evaluates the design and performance of the project.

RESERVOIR DESCRIPTION

The reservoir at the Loudon Field is a part of the Mississippian Chester Sandstone ranging in depth from 1,400 to 1,600 feet subsurface. Within the pilot area, the reservoir strata were deposited within a deltaic environment with distributary mouth bars and delta-front sands containing fine to medium grained, well-cemented sands with good reservoir continuity. The reservoir temperature is 78°F, the oil viscosity is 5 cp, and the formation water contains over 104,000 ppm TDS. Table 2 lists the rock and fluid properties for the pilot area.

Figure 1 shows the location of the Loudon pilot within the field. Figure 2 shows the location of wells within the pilot area. All ten of the wells comprising the pilot were new and were cored. As shown, there were four injection wells, one producer, and four observation wells. Nine of the ten wells were drilled and cored using a bland oil and a conventional core barrel. Cores from Wells 10, 11, 13, 14, and 18 were extracted to determine the residual oil saturation, and cores from Wells 9, 12, 15, and 16 were preserved for use in laboratory core floods. It was considered that the residual oil saturations were reasonably representative of reservoir saturations since the oil contains very little dissolved gas (and, therefore, little oil lost due to depressurization). A pressure core was collected in Well 17 as a check on the saturations obtained on the conventionally collected cores. The average oil saturation from that core closely agreed with the saturations from the conventional cores.

The core analysis results indicated the existence of three distinct but laterally continuous sandstone units. These data indicate that fluid communication across the pattern should be satisfactory.

The residual oil saturation varied from 22 percent pore volume to 36 percent pore volume. The average saturation in the pilot area was 25.4 percent pore volume, and the corresponding oil-in-place prior to the microemulsion flood was 3,420 barrels.

PROJECT DESIGN

PROCESS DESCRIPTION

Figure 3 shows the sequences of the fluids injected into the pilot area. Table 3 provides detailed specifications on the injected fluids.

The microemulsion was formulated by mixing a surfactant concentrate and biopolymer with the produced brine. The surfactant has not been specifically identified by Exxon in the literature. However, it is generally thought to be an ethylene oxide, propylene oxide sulfate surfactant. A 40 percent pore volume of a 2.3 weight percent surfactant was injected into the pilot area (assuming a pattern capture efficiency of 25 percent). Pfizer's FLOCON(R) 4800 biopolymer was added at a 1,000 ppm concentration. Isopropanol was also added as a material balance tracer.

An oxygen scavenger (sodium hydrosulfite) was added to the microemulsion fluid to prevent the oxidation of dissolved ferrous iron to the insoluble ferric form. Oxygen was excluded from the system by the use of nitrogen blankets on all surface facilities. In addition, acetic acid was added to prevent the formation of ferrous hydroxide. Further, a biocide was added to inhibit bacterial growth.

The polymer drive water contained the Pfizer biopolymer at a concentration of 1,400 ppm. The salinity of the water was reduced by mixing the produced brine with fresh water. As for the microemulsion, a biocide and oxygen scavenger were added and the pH adjusted to around 5.

TEST FACILITIES

Pre-Pilot Injectivity Test

An injectivity test was conducted in the Fall of 1979 in Mable Mills Well 16 (Figure 1) to establish mixing and quality control procedures prior to initiating the pilot. This test showed that (1) polymer solutions must be subjected to high shear to achieve good injectivity; (2) ferric iron in the fluids reduces injectivity due to the crosslinking and precipitation of the polymer; (3) complete exclusion of oxygen from the system is required; and (4) well head pressures of 400 psi or higher can induce fracturing.

Results of the tests were used to modify injection procedures for the pilot.

Injection Facilities

Surface facilities were used to blend, shear, filter, and inject the microemulsion and the polymer drive water. All tanks were internally coated with epoxy and all piping was either epoxy-coated steel or plastic. Nitrogen gas blankets were maintained on all tanks to exclude oxygen. All tanks were externally insulated with urethane foam to retain fluid temperatures near that of the reservoir and to maintain the microemulsion as a single phase. Reference 2 provides additional details on the injection facilities.

Production Facilities

Well 13 was produced by rod pump. The pumping time was periodically adjusted to achieve an overall fluid withdrawal equivalent to one-fourth of the total injection into the four wells.

The produced fluids entered a heater-treater which was equipped with electric heating elements. For the first six months, the separated fluids went directly into an oil stock tank and into a water stock tank. Later, the produced fluids were diverted into a 210 barrel settling tank to allow several days for separation of the fluids. This was required because of the emulsions that were being produced. Eventually, chemical de-emulsifiers were identified for controlling the emulsions. During the period of severe emulsion problems, the produced oil quantity was determined by measuring the total fluid volume and by laboratory tests to determine the oil content.

Down-Hole Pressure Monitors

Down-hole pressure measurements were made in three shut-in wells around the pilot: Wells L Ripley 1, 4, and 8 (Figure 1). The purpose of these measurements was to monitor the reservoir pressure gradients to detect any net migration of fluids into or away from the pilot area. If so, changes in the injection or withdrawal conditions could be made to help insure adequate response in the producing well.

The down-hole pressure in Well 13 was also continuously monitored. A Sperry-Sun pressure transmitter was installed below the rod pump in the well. This was accomplished by installing a packer below the pump but above the concentric pressure chamber located opposite the Weiler Formation. A special crossover sub was constructed to permit routing of the pressure responses through the packer. This installation permitted continuous monitoring of reservoir pressures in Well 13 and pressure buildup tests to be conveniently conducted without significant afterflow.

PROJECT IMPLEMENTATION

PRODUCTION RESPONSE

Figure 4 shows the oil response from Well 13. The tertiary oil response occurred at about 0.25 of the pore volume. The oil cut reached a maximum of about 26 percent. About 60 percent of the oil-in-place was recovered at 2.25 pore volume of production. The oil cut at this point declined to about 1 percent.

The most significant operational problem that occurred was the production of complex emulsions. Emulsions occurred at the time of surfactant breakthrough. Figure 5 shows the production of surfactant and polymer at Well 13. Up to about 0.7 pore volume of production, the emulsions were easily broken in the heater-treater by maintaining a temperature of 92 to 95°F for the 12 hours of residence time in the vessel. No de-emulsifier was required. Beyond 0.7 pore volume, the produced emulsions were more complex and more difficult to break. It was necessary to use commercial de-emulsifiers to break the emulsions.

Polymer response is also shown in Figure 5. The polymer broke through at a time which was expected. The relative (to injected) concentration of the produced polymer, however, was significantly below that of the produced surfactant and tracer concentrations. This information, along with other evidence, suggests that the polymer was being degraded.

About 60 percent of the surfactant injected into the pattern was produced. This number was derived by comparing the amount of surfactant produced with the amount of isopropanol produced. Isopropanol was injected along with the surfactant in all of the wells. About 14.3 percent of the total injected polymer was produced, compared to about 23 percent of the total injected isopropanol which was produced.

Comparison of the tracer responses shows relatively early breakthrough of the iodide tracer injected into Well 11. Injection flow profiles run in Well 11 near the end of microemulsion injection showed that almost all of the injected fluids were entering the bottom three feet of the pay. The early tracer response and the poor injection profile together indicate that the sweep efficiency in the 11 quadrant is low. The reason for the poor sweep is unknown, since injection profiles prior to microemulsion injection indicated good vertical flow distribution. The nitrate tracer injected into Well 11 was never observed in the producing well, suggesting either adsorption or biological degradation.

OBSERVATION WELL RESPONSES

Induction logs and carbon/oxygen (C/O) logs run in the observation wells provided additional data for evaluating the pilot. In general, the logs were very helpful in defining stratification within the formation and in measuring saturation changes as a function of the distance from the injection wells.

The log response in the observation wells shows the build-up of oil saturations with time, and then the decrease in saturations as the tertiary bank is displaced toward the producing well. The lower zone was generally better swept than the upper zone. Induction logs run on Well 12 indicate good displacement of oil from the lower zone, but little displacement of oil from the upper zone. This supports the earlier mentioned observations concerning poor injection profiles in the injection Well 11 and the early interwell breakthrough response from that quadrant.

POLYMER DEGRADATION

There are several indications that the biopolymer was bacterially degraded for a period of time beginning after about 0.65 pore volume of production. The injectivity of fluids at Well 11 increased at that point in time. Samples from observation wells collected during the prior to the period of March to April, 1981, indicated a total loss of polymer viscosity and the existence of bacteria known to degrade the biopolymer. An examination of retained polymer injection samples indicated that solutions had retained their viscosities except during the period of November 21 to December 4, 1980. Those samples had lost their viscosity and there was evidence of organisms capable of destroying the polymer.

Later research indicated that reactions were occurring between the DBNPA biocide and the D-OX(R) oxygen scavenger. These actions nullified the effectiveness of the biocide making polymers susceptible to degradation.

PROJECT EVALUATION

PROJECT DESIGN

The Loudon pilot was conducted to evaluate some basic concepts in the design of surfactant floods. The following are two distinct design criteria which differed from earlier projects:

1. A chemical system was designed for the high salinity, high-hardness formation water which existed in the reservoir. Earlier projects in a large number of fields used a preflush water to remove excessive hardness and to adjust the salinity to the proper level for efficient displacement of oil.

2. The chemical system was designed to eliminate the "co-surfactant" which is normally present. The traditional functions of the co-surfactant are to help improve the displacement efficiency, increase the hardness tolerance, and reduce the adsorption of the surfactant.

In essence, the pilot was set up as a carefully controlled research and development project conducted under field conditions. There were a number of operations which may not exist in a commercial operation. These include the drilling of all new wells, coring of all wells, use of pressure cores, use of observation wells, use of interwell tracers, use of one post-project cored well, and use of pressure-monitoring wells. All of the operations contribute toward a better understanding of the process, but also contribute significantly to costs.

The operator also chose to evaluate the process in a small-acreage, normal 5-spot pattern using extensive evaluation procedures. The alternative approach was to conduct the project in a larger, multi-pattern area using less precise procedures for monitoring performance. The pilot was clearly interpretable in this application since the reservoir characteristics were reasonably uniform and were well defined by the evaluation procedures.

In our opinion, the project was very well designed and executed. We concur with the basic concept that the chemical system must be tailored for the salinity and hardness of the formation water. Our review of numerous chemical projects indicates that preflushes designed to remove hardness or to adjust salinities have generally been unsuccessful, even if the reservoir had been waterflooded with a fresh water.[4] Preflushes can fail for various reasons. For example, connate water may be shielded by oil in oil-wet systems and not susceptible to displacement by injected water. "Pockets" of connate water may not have been displaced by injection water due to reservoir heterogeneities. Injection of a microemulsion may contact the "trapped" and "bypassed" connate water by miscibly removing the oil and by sweeping a greater portion of the reservoir due to the reduced mobility fluid. Preflushes also may have been ineffective in removing the hardness associated with clay minerals.

We also concur that co-surfactants should be eliminated as a separate component from the microemulsion. The surfactant and co-surfactant tend to become separated from each other or to change in relative proportions as fluids move through the reservoir. A single surfactant, with the chemistry incorporated within a single molecule, should continue to be effective even as concentrations are reduced (due to adsorption or phase transfer).

OIL RECOVERY PERFORMANCE

As earlier discussed, about 60 percent of the oil-in-place at the start of the project was recovered by the process. This amounted to about 2,050 barrels of oil. The recovery projection is considered reasonably accurate since the oil saturation was well defined and the oil production was carefully measured. This recovery is substantially higher than most surfactant floods, particularly considering the salinity of the formation water. Figure 6, from Reference 4, shows the recovery efficiency of various projects. As shown, the Exxon Loudon test stands out in comparison with other projects for its high oil recovery.

Another measure of performance is the surfactant utilization, which is defined as the pounds of surfactant required per barrel of oil produced. This number is as follows:

Surfactant Utilization = [Pounds of Surfactant Injected into Pilot]/[Barrels of Oil Recovered]

Surfactant Utilization = (0.025) (189,000 lbs)/2,050 bbls = 23 lbs/bbl

The above number assumes that 25 percent of the injected surfactant went into the pattern area. Considering that about 60 percent of the injected surfactant was produced (40 percent lost), the more significant number is:

Adjusted Surfactant Utilization = [Pounds of Surfactant Lost Within Pilot Area]/[Barrels of Oil Recovery]

Adjusted Surfactant Utilization = (0.40) (0.25) 189,000/2,050 = 9.2 lbs/bbl

The surfactant utilization is low compared to most other surfactant projects. Surfactant utilization is typically in the range of 20 for projects where significant oil was recovered. The comparison of the Loudon number with these other projects needs to be qualified, since no adjustment was made for the amount of produced surfactant in the other tests. Generally, the adjustment would be small in those other projects since little (relative to the injected quantity) surfactant was produced.

The significance of the surfactant utilization factor is that a quick estimate can be made on the efficiency of the process and the costs required for the major chemical component per barrel of oil produced. Similar numbers can be derived for the injected polymer, which is normally a much lower cost component.

Although a 40 percent pore volume surfactant slug was used in the pilot, a commercial operation would require a significantly reduced quantity. Since 60 percent of the injected surfactant was produced, it can be estimated that 40 percent of the designed quantity (16 percent pore volume) would be sufficient to penetrate to the producing well. The ultimate effect of the smaller slug size on recovery would have to be evaluated.

The surfactant loss was also computed for the pilot area by the following procedure.

$$\underset{\text{(lbs/bbl)}}{\text{Surfactant Loss}} = \frac{(0.25)\ (189{,}000)\ (0.40)\ \text{lbs}}{13{,}500\ \text{bbls}}$$

$$= 1.4\ \text{lbs/bbl pore space}$$

This loss is considered to be low relative to many other projects. The number was computed by dividing the total pounds of active surfactant lost within the pattern area divided by the pore volume of the pattern. The number is an approximation since the injected fluids contacted an unknown portion of the reservoir.

RESERVOIR CHARACTERIZATION

The pilot area was extremely well characterized. Reservoir rock and fluid properties were characterized by the use of well logs and the coring of all new wells within the pattern including one pressure core. The evidence was strong that acceptable reservoir continuity existed between wells prior to the start of the project. Reservoir heterogeneities have been a major cause for poor performance and poor interpretability in other projects. Performance was gauged not only by analysis of the fluids produced from Well 13, but also by the monitor wells, pressure monitoring wells, and by the post-project cored well. Results of the post-project core analysis are not known to us.

POLYMER DEGRADATION

As earlier discussed, difficulties were encountered in maintaining the stability of the biopolymer during one period of time. This problem appeared not to significantly affect the overall performance of the project. The evidence was strong that the polymer degraded due to microbiological activity. Also, it appeared that the effectiveness of the biocide was being lost by reaction with the oxygen scavenger.

Microbial degradation of biopolymers has also occurred in other projects. It is likely that problems were less severe at Loudon since microbial activity is inhibited in highly saline water. Our opinion is that the operator used state-of-the-art technology in attempting to stabilize the polymer. This experience reinforces the need for additional research to improve the tolerance of biopolymers to microbial degradation.

Complete details of the biocide program were not made available, so we can only make some general comments. It is not known if the biocide achieved a total kill of bacteria. Without a total kill, there is the tendency of a buildup of bacteria concentration at the wellbore because of their inability to propagate through the reservoir. Microgels also tend to build up around the injection face, which effectively increases the polymer concentration. Although the biocide may control microbial activity in the surface facilities, the buildup of bacteria and polymer concentrations at the injection face provides conditions which could lead to biodegradation. Once started, the biodegradation process is very difficult to control.

Achieving a total kill of bacteria is very difficult with existing biocides. Acrolein is effective but has its limitations. Chlorinated compounds (e.g., chlorine gas, hypochlorite) are also potent biocides and could have been used for achieving a total kill in Loudon. However, the use of such compounds also has disadvantages arising from safety concerns and from their corrosive nature. An effective biocide program without excessive corrosiveness can be achieved by maintaining a chlorine biocide concentration slightly in excess (e.g., 1/2 ppm) of that required for a total kill. However, such a program will require a frequent and time-consuming monitoring operation.

Other biocides, such as formaldehyde and glutaraldehyde, have advantages in their ease of use. However, there does not appear to be a biocide which is sufficiently potent and yet does not have some significant disadvantages in its use.

TRACER PROGRAM

The tracer program was reasonably designed, considering the number of tracers required and the availability of suitable tracers. The use of isopropanol in the microemulsion injected into all four wells is questionable in view of mixed industry experience. Isopropanol is sometimes biodegraded. Ethanol and methanol are often biodegraded. These alcohols, however, are less likely to be biologically attacked in the high salinity brine. Iodide and bromide tracers are generally suitable if the background concentrations are sufficiently low.

The tracers injected with the polymer are often suspect. Without using radioactive tracers, the choices of tracers are limited. The nitrate can be lost due to biodegradation or to reaction with the reservoir or injection water, which probably explains why it was not detected in offset wells. T-butanol may be partially lost to the oil phase, especially since the salinity of the water was high. The thiocyanate is generally a satisfactory tracer.

Several radioactive tracers would have been suitable from a performance standpoint. These include tritiated water and several cobalt isotopes. These tracers can be safely used provided that regulations of the Nuclear Regulatory Commission are followed during injection and sampling. It is not clear why these were not used in Loudon. In particular, the tritiated water would have been a very suitable tracer to be injected with the microemulsion.

CONCLUSIONS

A successful surfactant flood has been conducted in the Loudon Field, Fayette County, Illinois. This reservoir contained a formation water having a salinity of 104,000 ppm. The following are the major conclusions from our review of the project.

1. The project recovered about 60 percent of the residual oil saturation within the pattern area, and oil cuts as high as 26 percent were attained. This recovery level is very high relative to most other projects and is particularly significant in view of the high salinity formation water.

2. About 60 percent of the surfactant injected into the pattern was produced. This suggests that a quantity significantly lower than the 40 percent pore volumes injected would be suitable for future tests. Considering the amount of surfactant produced, it was estimated that the surfactant requirements are about 9 pounds (active) per barrel of oil produced.

3. The project was very well designed and executed. The following are the factors which we think contributed significantly to its success.

    A. Use of a chemical system which is designed for the formation water salinity and which avoids the need for a surfactant. Such a chemical system avoids the need for a preflush to remove excessive salinity and hardness. Preflushes have generally been unsuccessful.

    B. Favorable reservoir conditions including good interwell continuity, adequate oil saturation, relatively high permeability, and small pattern size.

C. Operating conditions were carefully controlled to avoid pressure parting. Pattern balancing was used to insure that the designed surfactant quantity entered the pattern area, and pressure monitoring wells were used to help insure that there was no large scale migration of fluids outside of the pattern.

4. The project could be clearly interpreted. The factors which contributed significantly were:

   A. Core analysis, well log analysis. All new wells were drilled, cored, and logged. These sources provided useful information on rock properties and fluid saturations.

   B. Interwell tracers for monitoring the movement of the microemulsion and the polymer and providing the reference point for computing surfactant adsorption.

   C. Monitor wells to provide early indications of project performance.

   D. Post-project cored well for evaluating performance.

   E. Injection profile surveys to help evaluate sweep efficiency.

5. Two operational problems developed during the course of the project. These were emulsion problems that developed after surfactant breakthrough, and polymer degradation.

RECOMMENDATIONS

The Loudon pilot has contributed greatly toward the development of chemical technology for recovering oil from low pressure, shallow oil reservoirs. Such technology is needed as a complement to other EOR processes (e.g., thermal, miscible gas) since a significant resource base exists in reservoirs where only chemical flood technology could potentially apply. The importance of the project has been the demonstration that a surfactant, which is chemically tailored for the reservoir, can recover a significant amount of oil. Although the total project cost was high in this application, the potential exists for extending the technology to other locations on a commercial basis.

The next step is to evaluate the technology on a wider-scale, commercial basis. Such a project should be implemented with multiple patterns, wider spacing, smaller slug sizes, and fewer controls which contributed mainly toward interpretation (e.g., observation wells, post-project wells).

This project, along with others, has demonstrated the need for a better understanding of the many complex and interrelated factors which influence the degradation of biopolymers. Biocides are needed which can effectively protect biopolymers from microbial degradation. Such a biocide must be convenient to use, economically feasible, and have the capability of achieving a total kill of the bacterial colonies.

TABLE 1

TYPICAL ANALYSIS OF LOUDON FORMATION BRINE

Ion	Milligrams Per Liter
Sodium	36,130
Calcium	2,840
Magnesium	1,210
Barium	63
Chloride	64,220
Bicarbonate	141
Iron	12
	104,616

TABLE 2

PROPERTIES OF THE PILOT AREA

Average Permeability	150 md
Average Porosity	19%
Average Thickness	13 feet
Depth	1,550 feet
Temperature	78°F
Average Oil Saturation Prior to Pilot	25.4%
Area of Pilot	0.68 acres
Pore Volume	13,500 barrels
Oil-In-Place Prior to Pilot	3,430 barrels

TABLE 3

SPECIFICATION OF INJECTED FLUIDS

Microemulsion

Surfactant	Oxyalylated Sulfate
Concentration of Surfactant	2.3 wt %
Quantity Injected (volume)	21,854 bbls (40% PV into pattern area assuming 25% capture)
Quantity Injected (weight)	189,000 lbs (active basis)
Polymer	Pfizer FLOCON(R) 4800 Xanthan Polymer
Concentration of Polymer	1,000 ppm
Additives	
Oxygen Scavenger	75 ppm D-OX(R) (sodium hydrosulfite)
pH adjustment to 5	acetic acid
Biocide	10 ppm DBNPA (dibromo nitrilo propionamide)

Polymer

Type	Pfizer FLOCON(R) Xanthan Biopolymer
Concentration	1,400 ppm
Additives	
Oxygen Scavenger	D-OX(R)
pH adjustment to 5	acetic acid
Biocide	DBNPA

Tracers

Well 10	930 ppm ethanol
Well 11	440 ppm iodide
Well 14	690 ppm bromide
Well 18	925 ppm methanol
All Wells	650 ppm isopropanol

Tracers (with polymer)

Well 10	1,260 ppm t-butanol
Well 11	260 ppm nitrate
Well 14	none
Well 18	380 ppm thiocyanate

FIGURE 1

LOCATION OF THE LOUDON PILOT

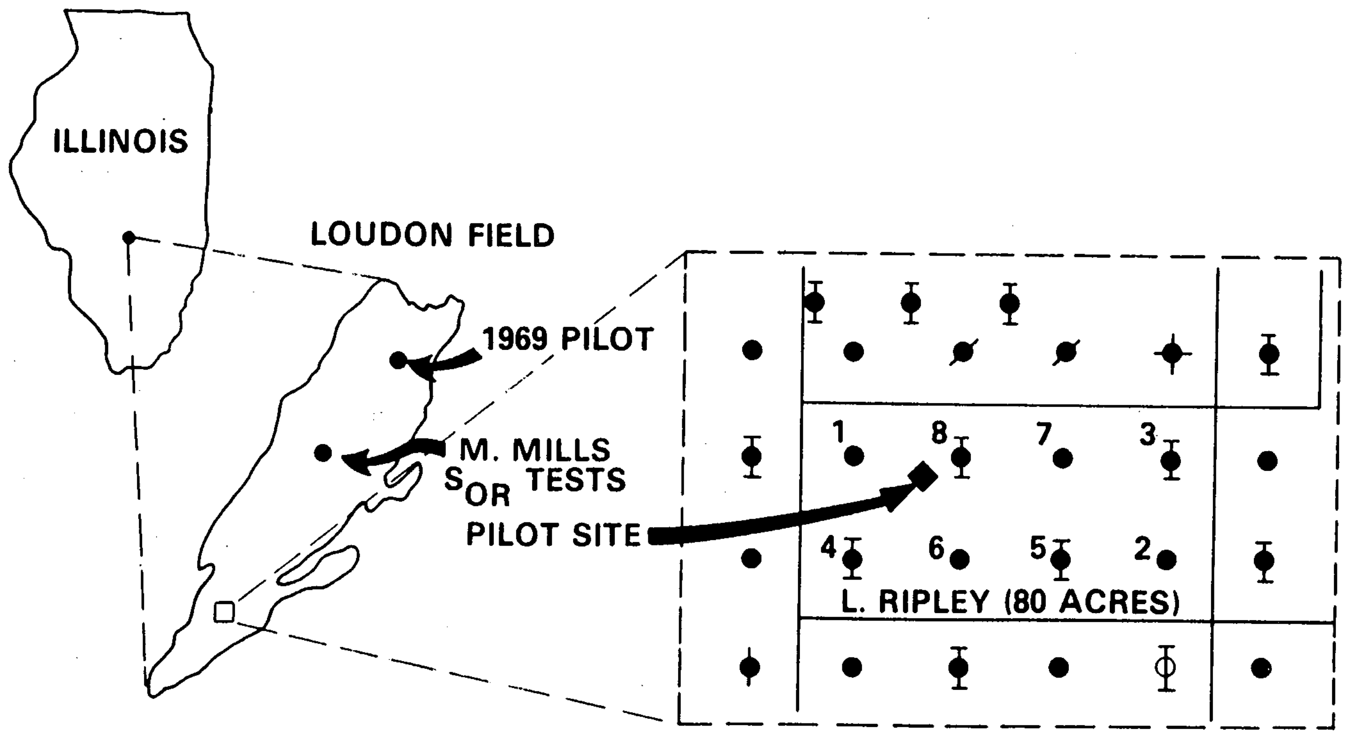


FIGURE 2

LOUDON PILOT PATTERN

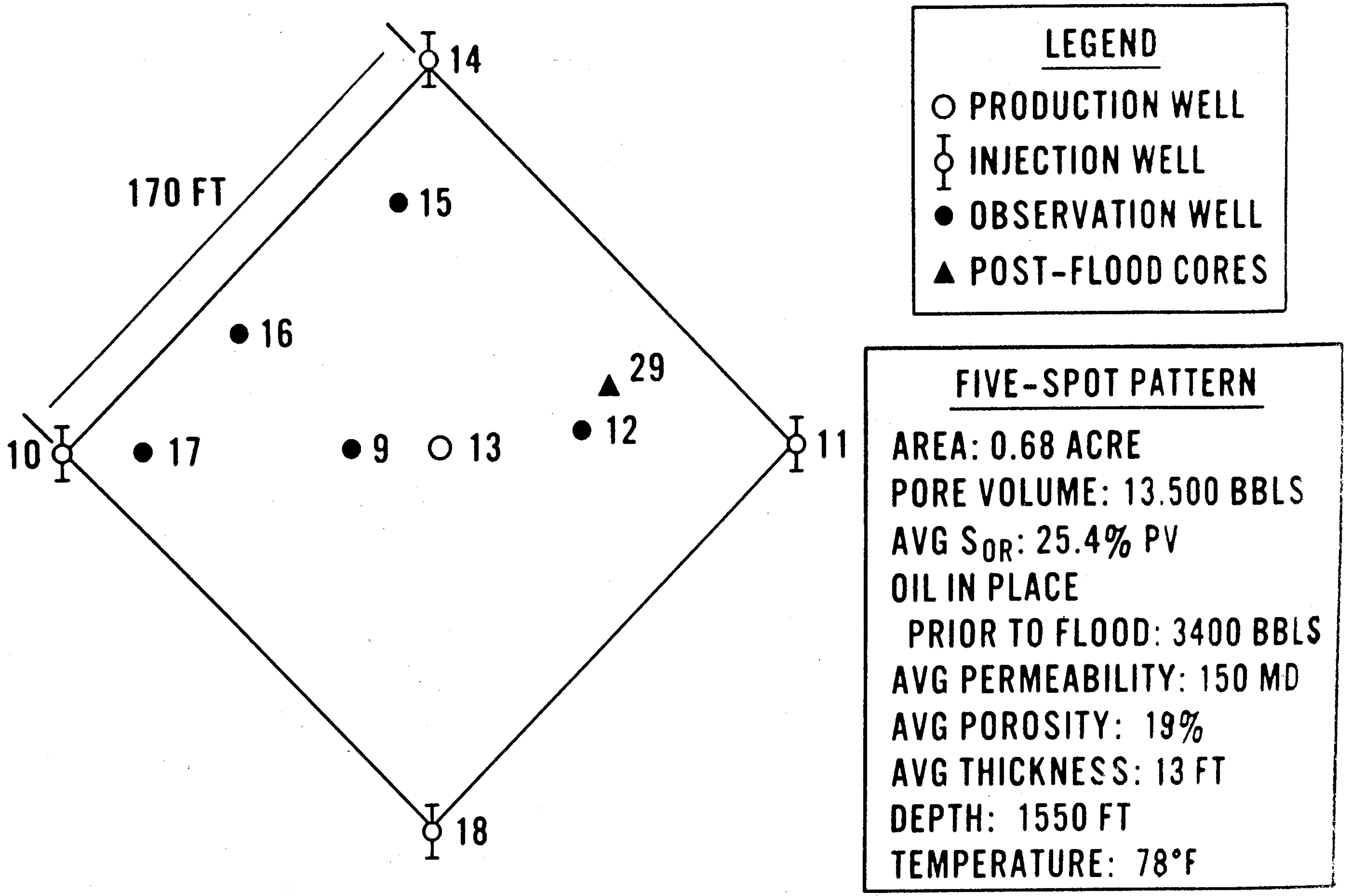


FIGURE 3

CHEMICAL SYSTEM – LOUDON PILOT TEST

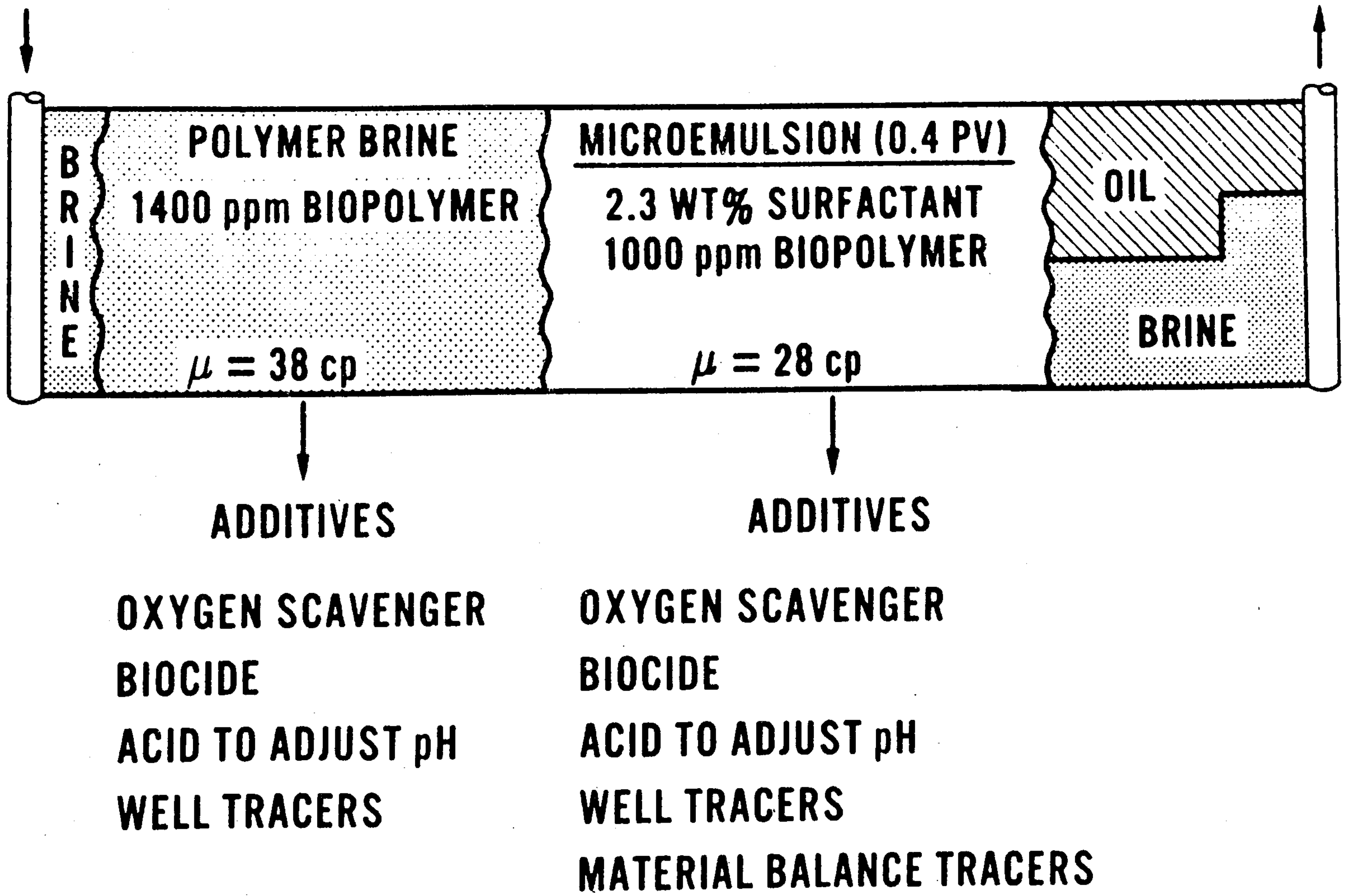


FIGURE 4

PILOT OIL PRODUCTION FROM WELL 13

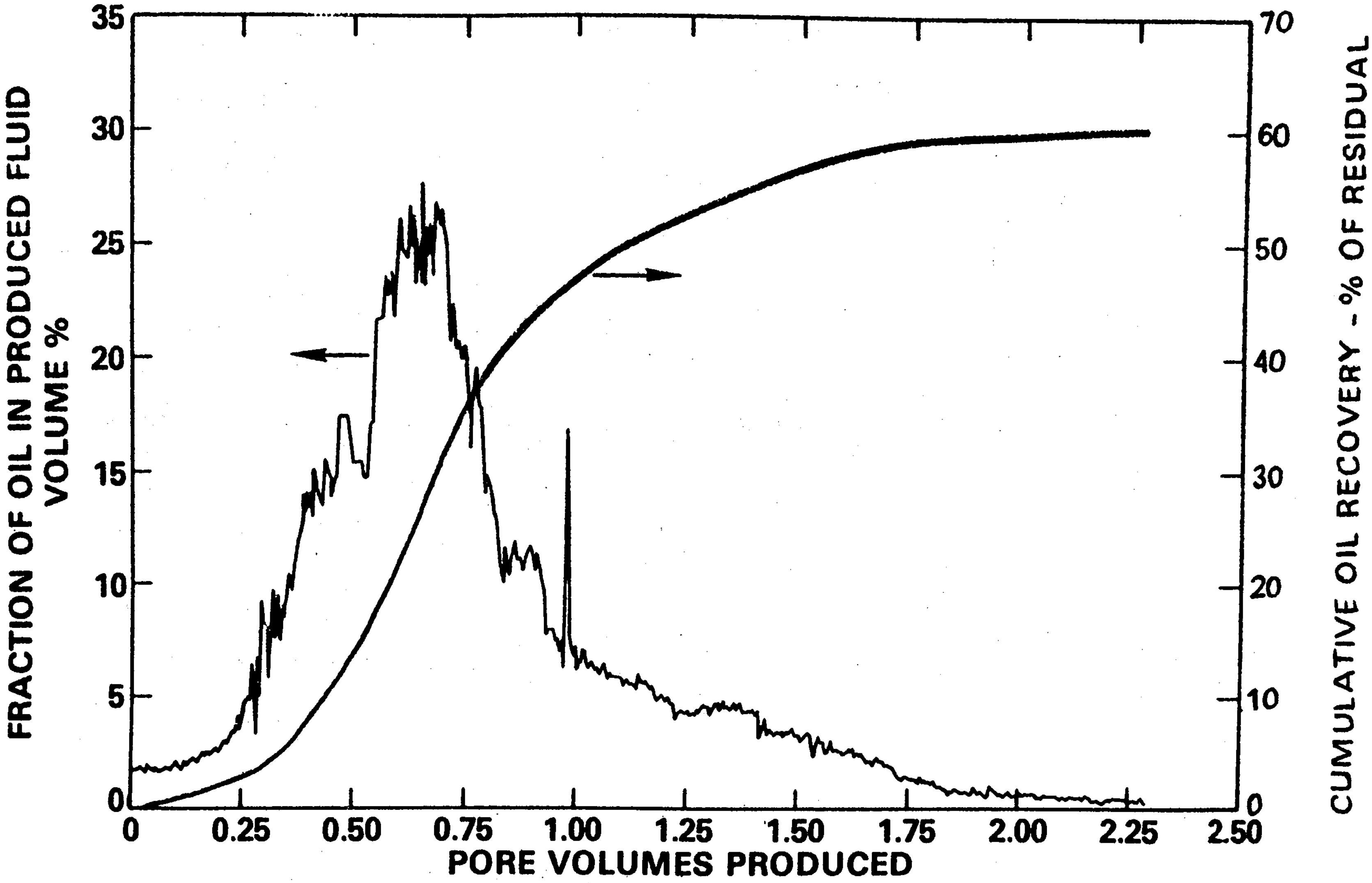


FIGURE 5

CONCENTRATIONS OF SURFACTANT AND POLYMER IN PRODUCED FLUID

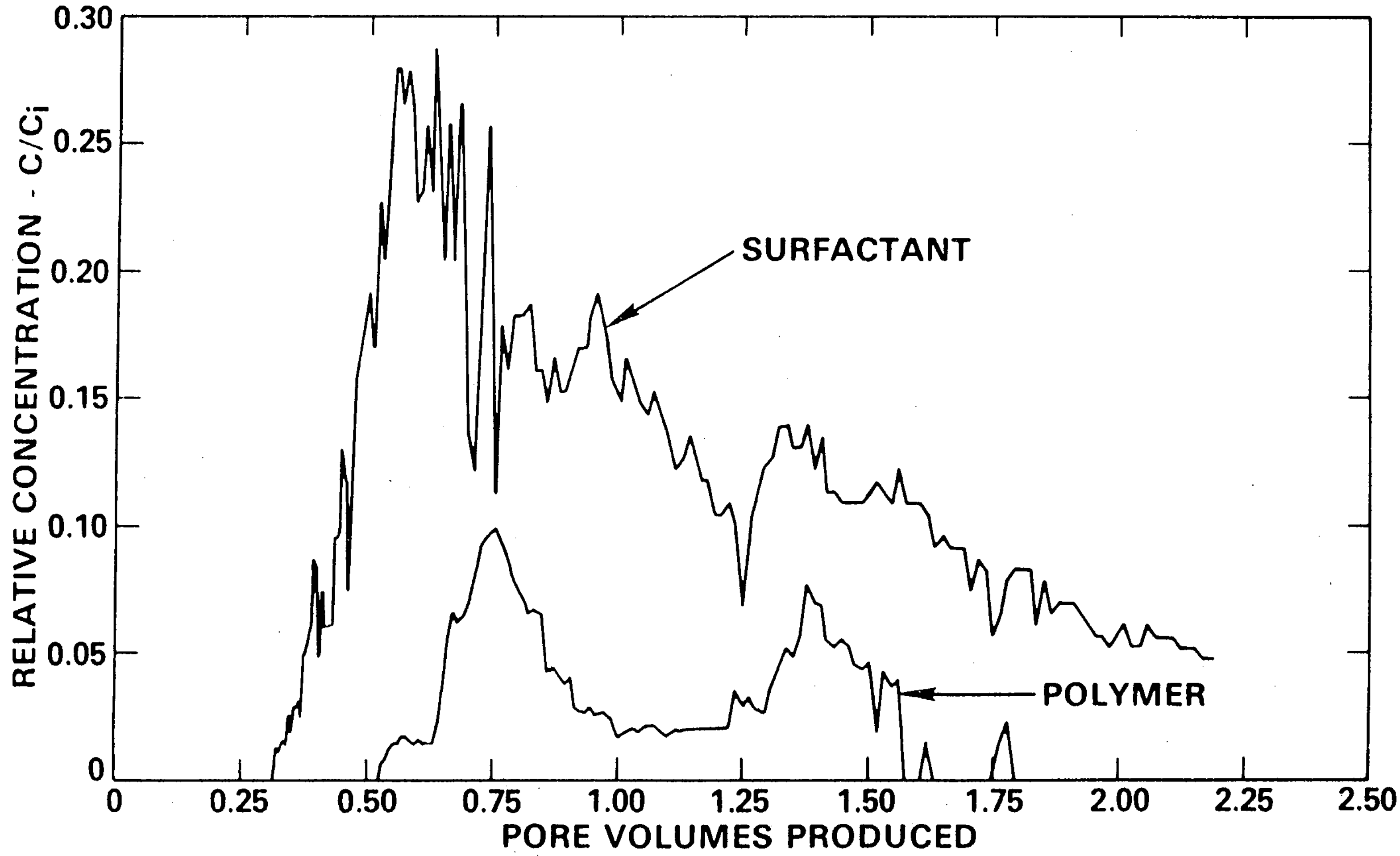
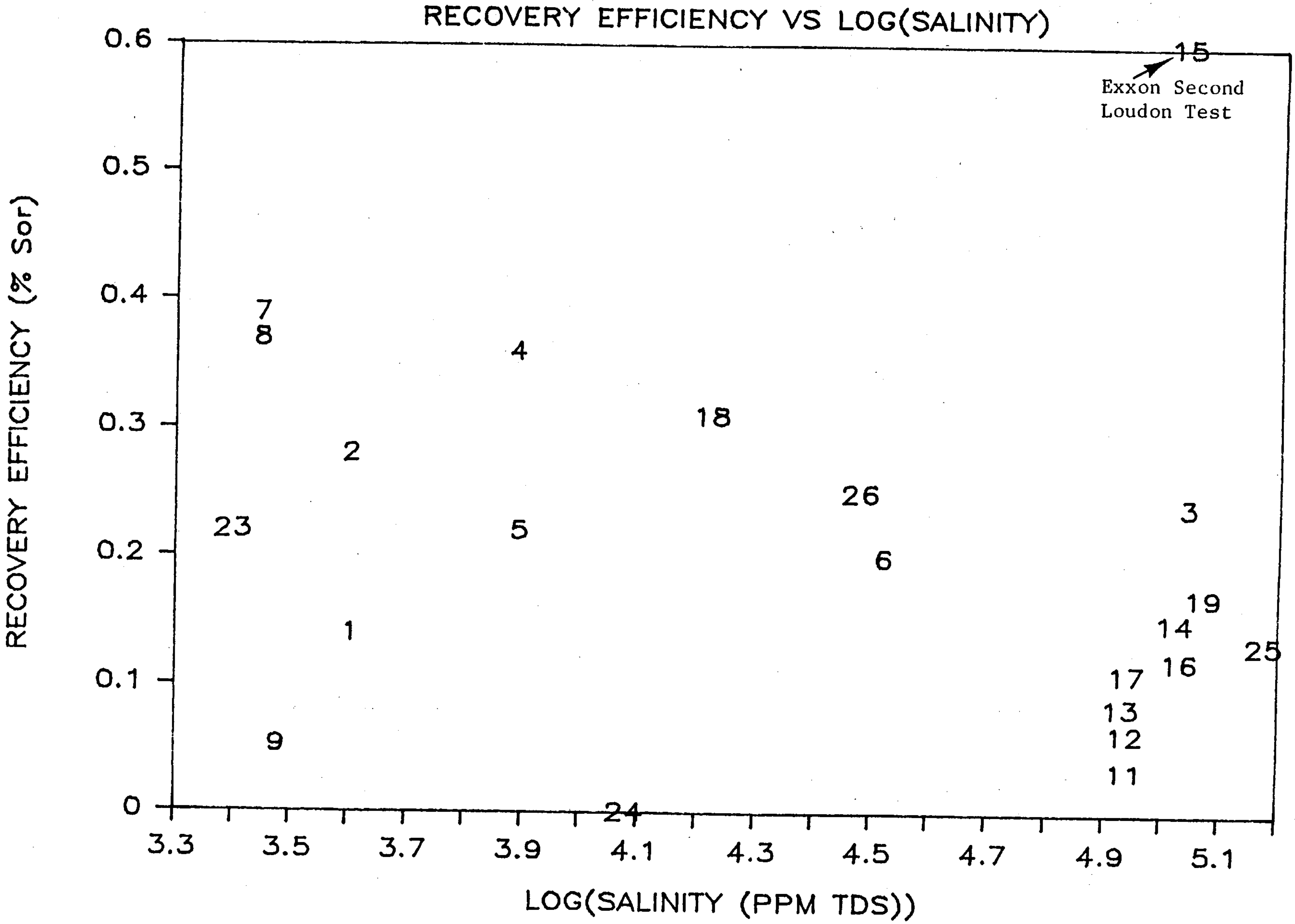


FIGURE 6

SALINITY EFFECT



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